Space Astronomy towards the New Millenium

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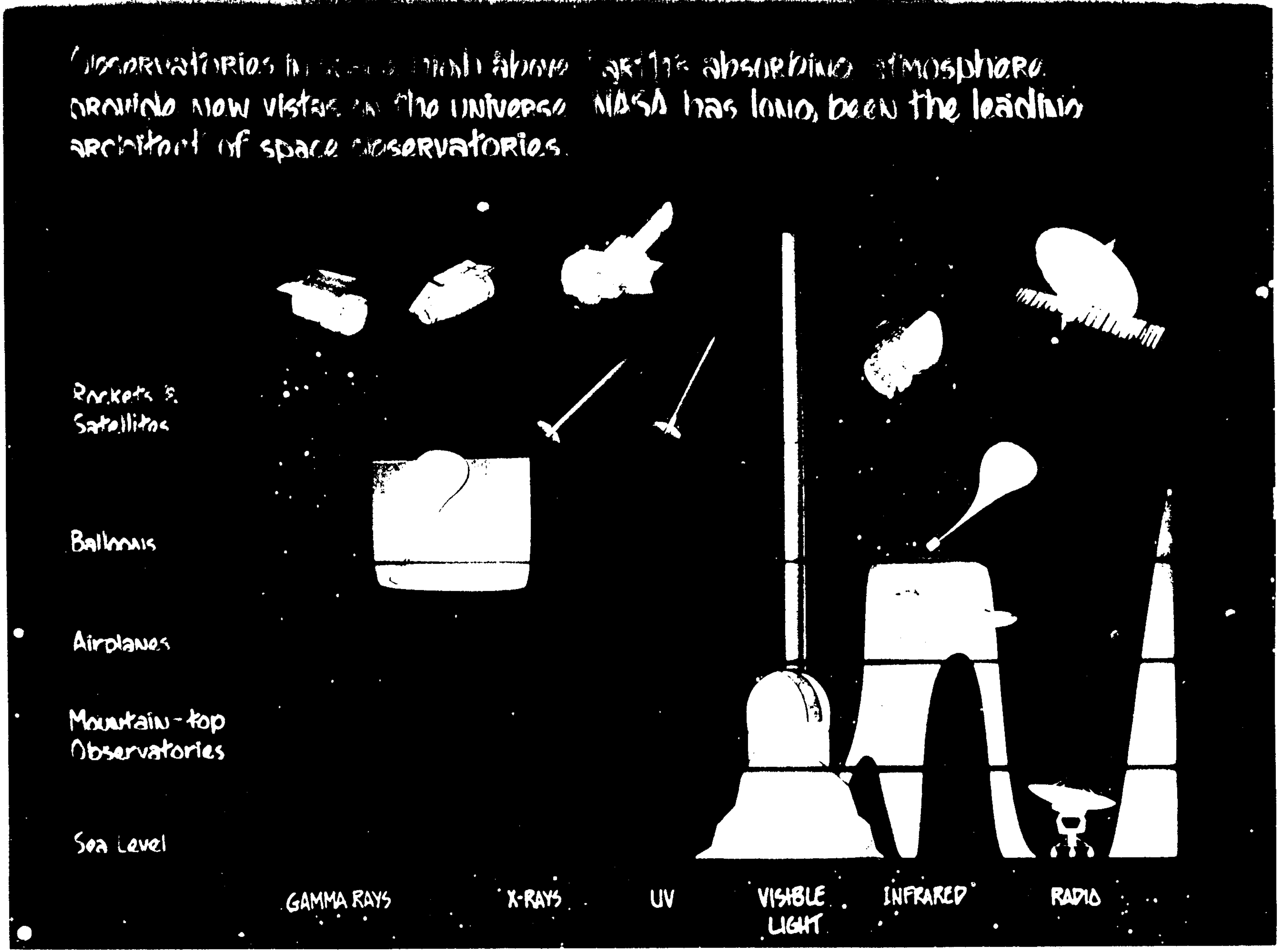
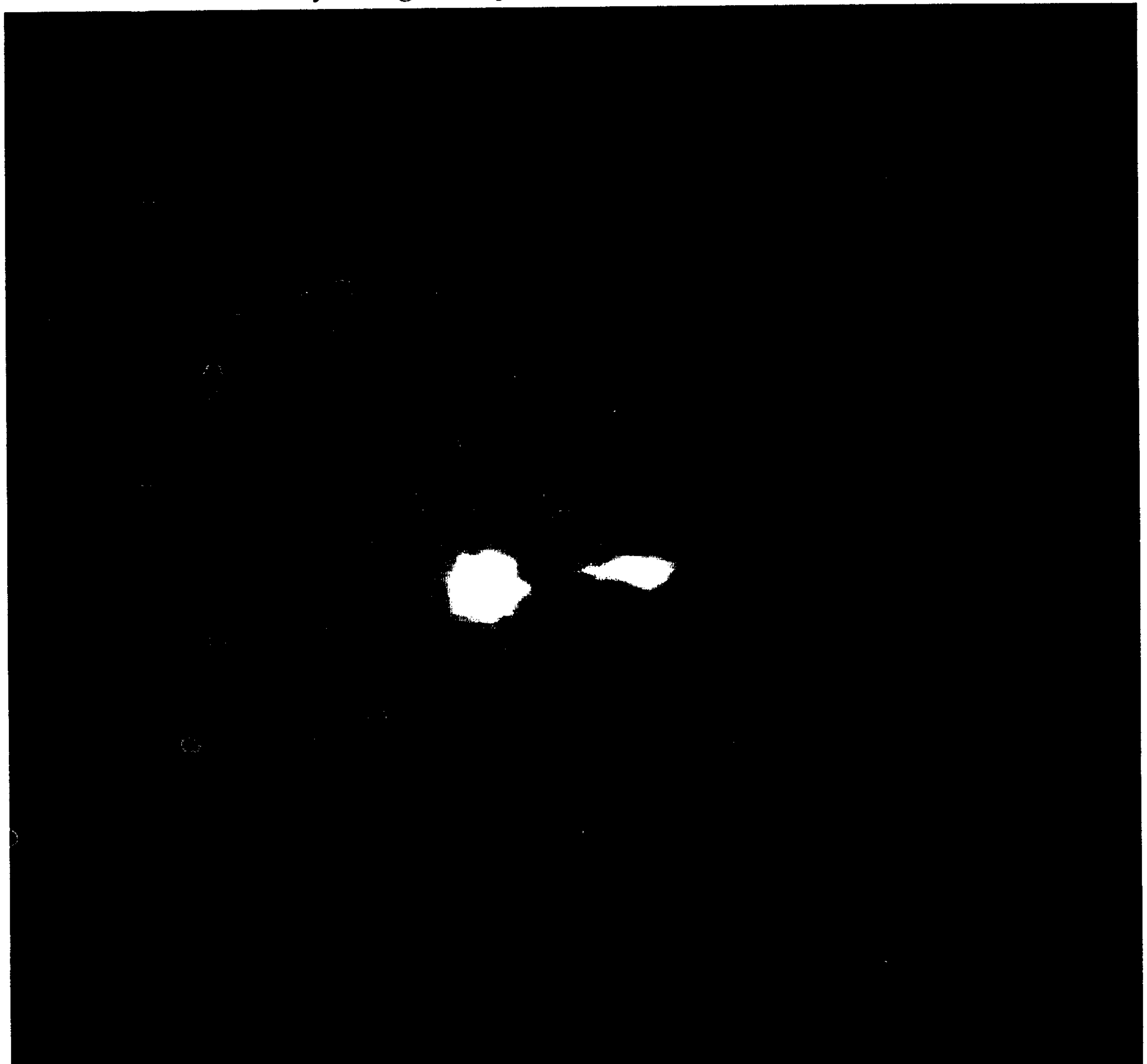
4 Great Observatories
Temperature they operate in

I only have
[illegible] of this



MUD-3
I only have ,

4 Great Observatories,
why observe from space



First Test Picture of Chandra - PKS 0637-752

STS-93 Shuttle Crew

Tognini

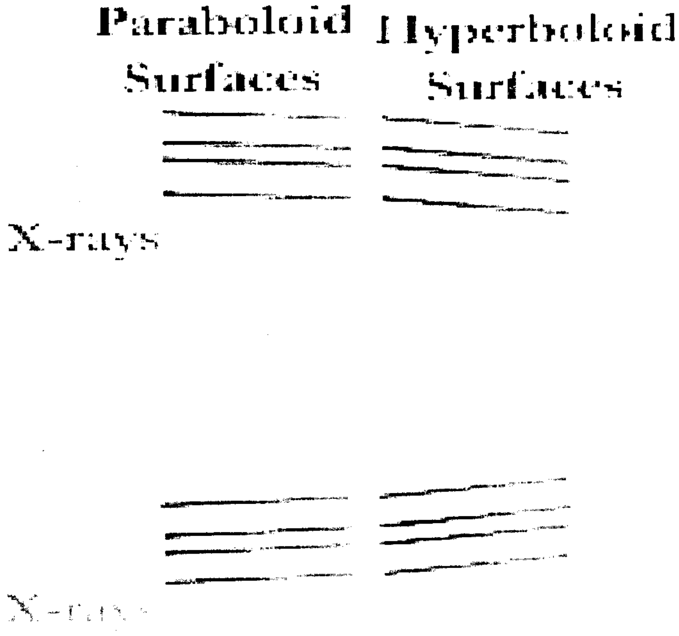
Coleman

Collins

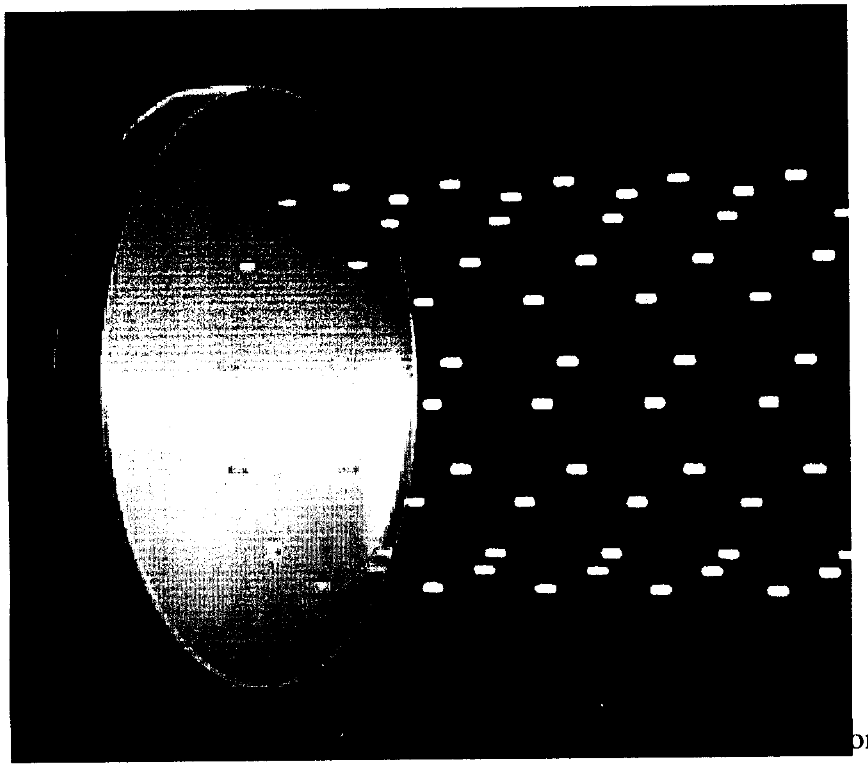
Hawley

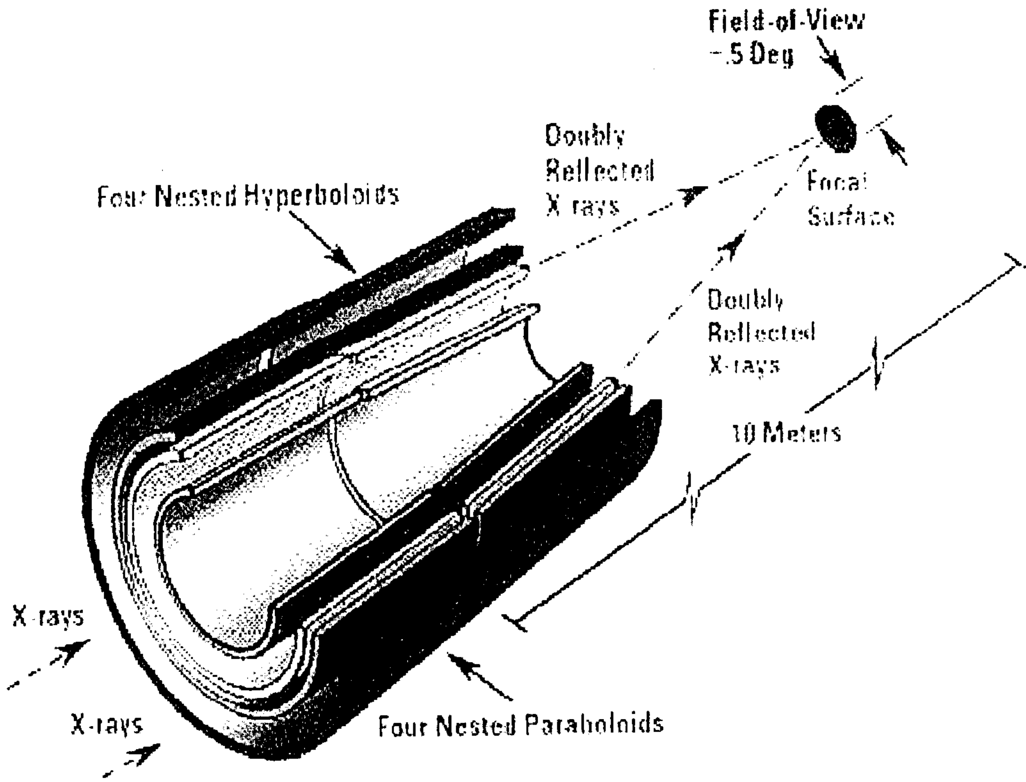
Ashby

Special Mirrors



Focal Point





Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter

Chandra Instruments

Charged Coupled Imaging Spectrometer (ACIS):

- 2 CCD arrays can provide simultaneous time-resolved imaging and low resolution spectroscopy
- High resolution spectroscopy can also be obtained
- ACIS has an energy range of 0.2 - 10 keV
- The imaging field of view is 16 x 16 arcmin

High Resolution Camera (HRC):

- Microchannel plate detector with energy range 0.1 - 1- keV
- HRC has higher spatial resolution than HRC (Joy????)
- Two detectors, one optimized for imaging and the other optimized for spectra, especially the Low Energy Transmission Grating (LETG)
- The imaging field of view is 30 x 30 arcmin ghost-free
- Spatial resolution is approximately 0.5 arcsec

High Energy Transmission Grating (HETG):

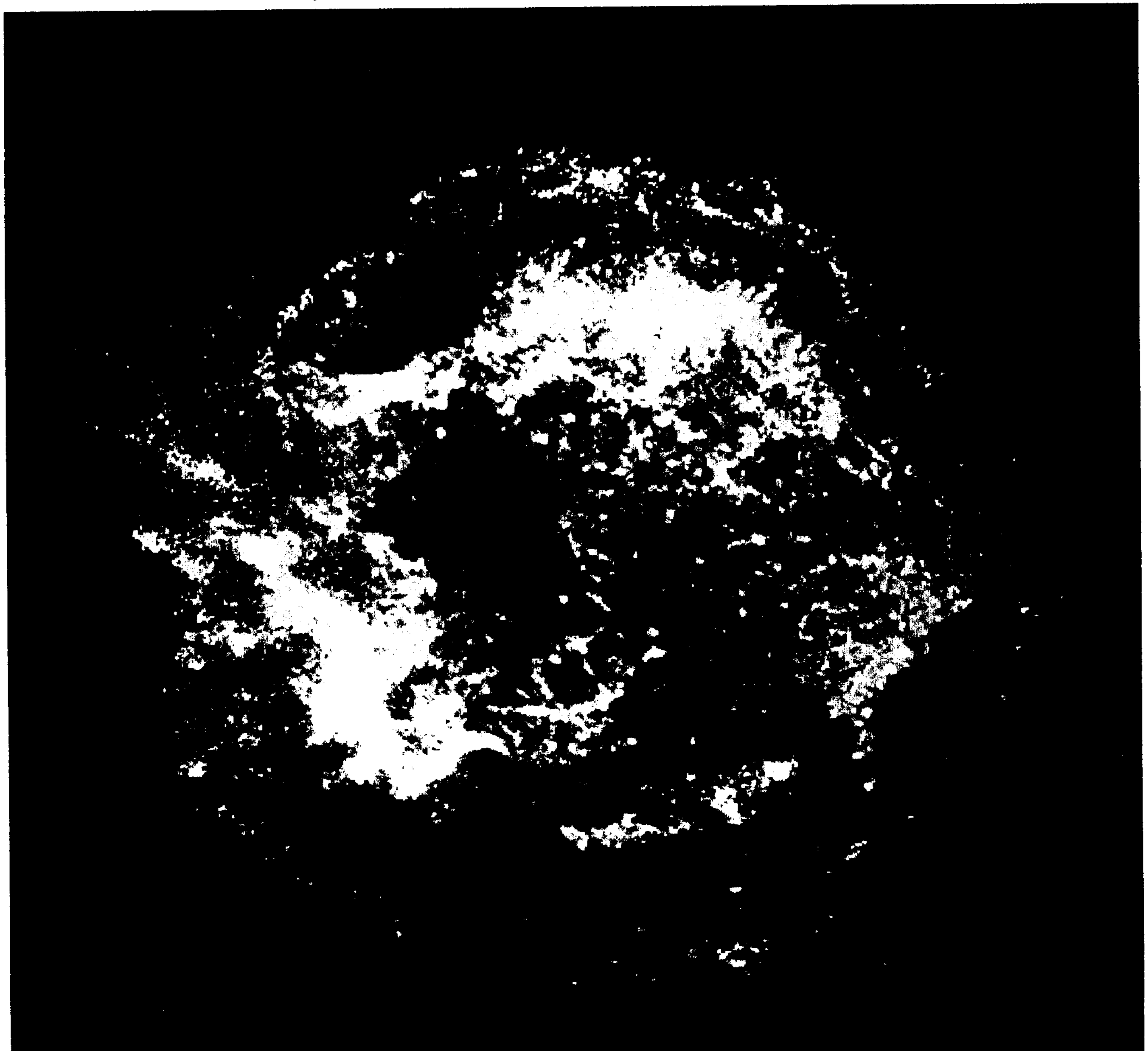
- 0.5 - 10 keV; E/delta(E) = 60 - 1000 (energy dependent)

Low Energy Transmission Grating (LETG):

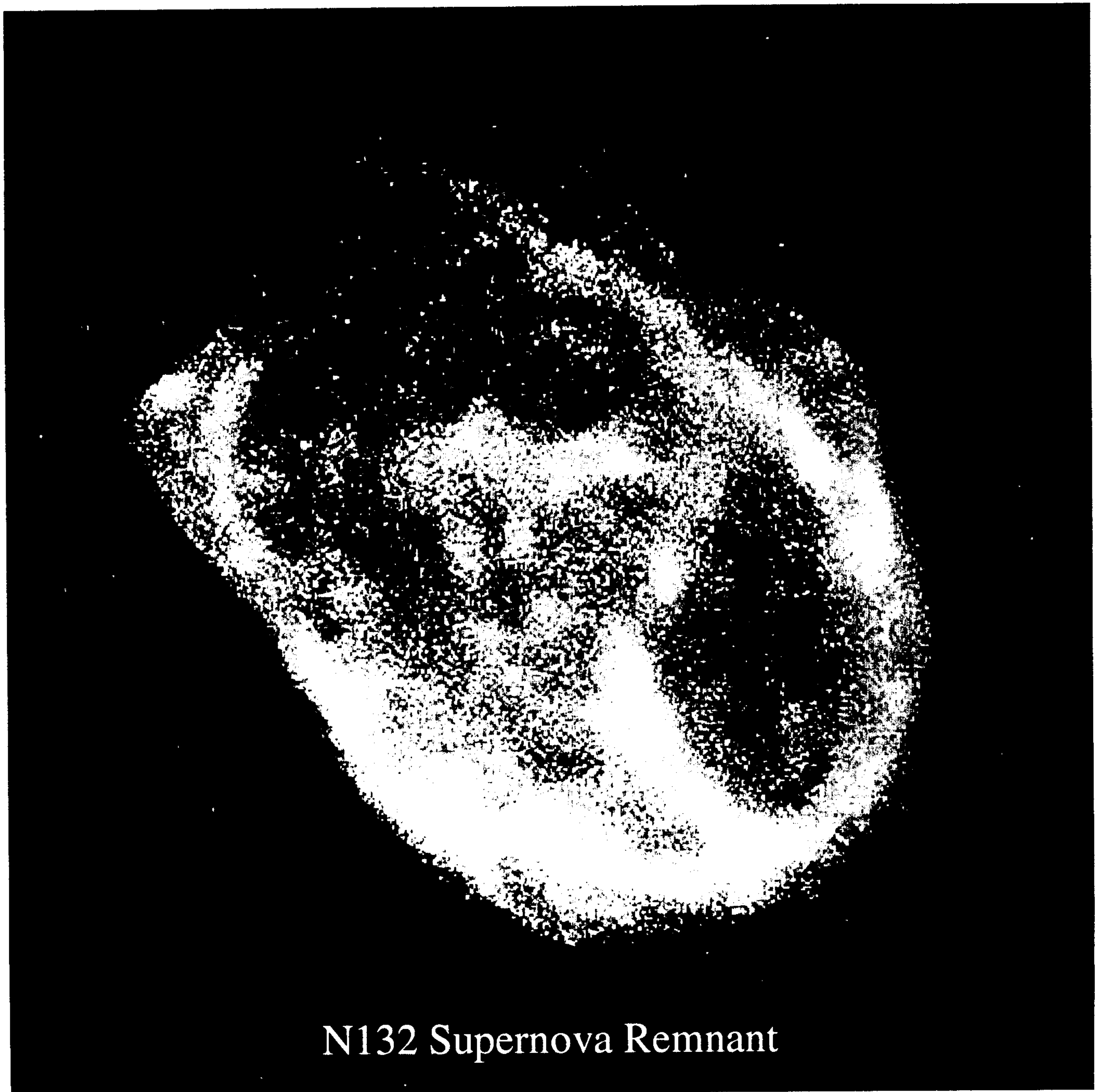
- 0.08 - 6 keV; e/delta(E) = 30 - 2000

Chandra Science Objectives

- Study of the violent universe, of phenomena that release so much energy that they shine brightest at x-ray wavelengths:
    - high-temperature and high-velocity gases (millions of degrees Celsius)
    - death or stars or colliding galaxies,
    - stars that explode and release elements from their hearts
    - matter sucked into massive black holes
    - quasars to neutron stars
- Record the position of the x-rays
- Determine color (energy) of the x-rays; capable of distinguishing 50 different energies



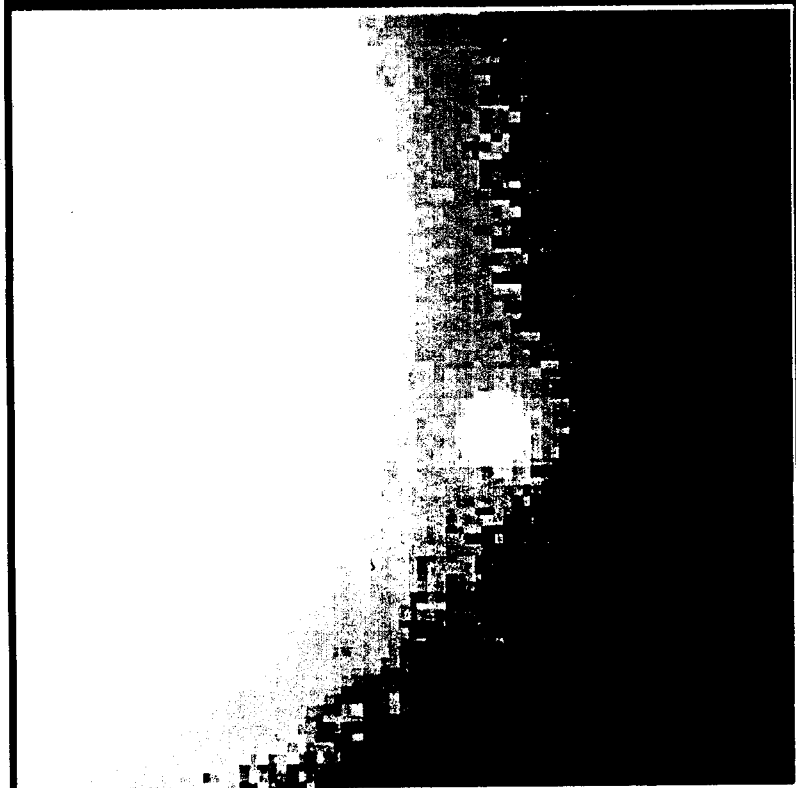
Cassiopeia A Supernova


N132 Supernova Remnant

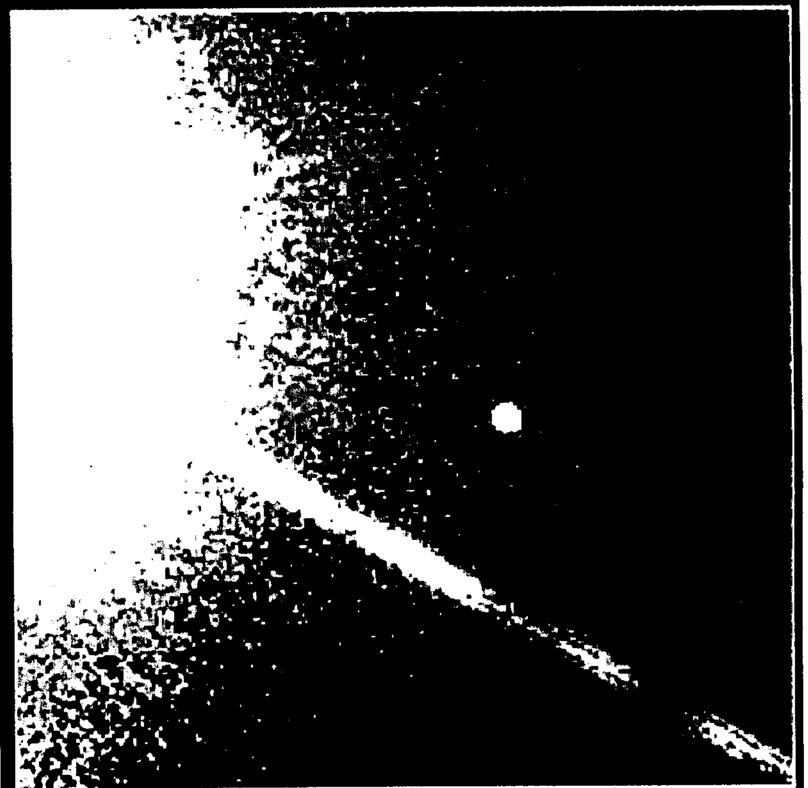
EM spectrum

SIRTF

Brown Dwarf Gliese 229B

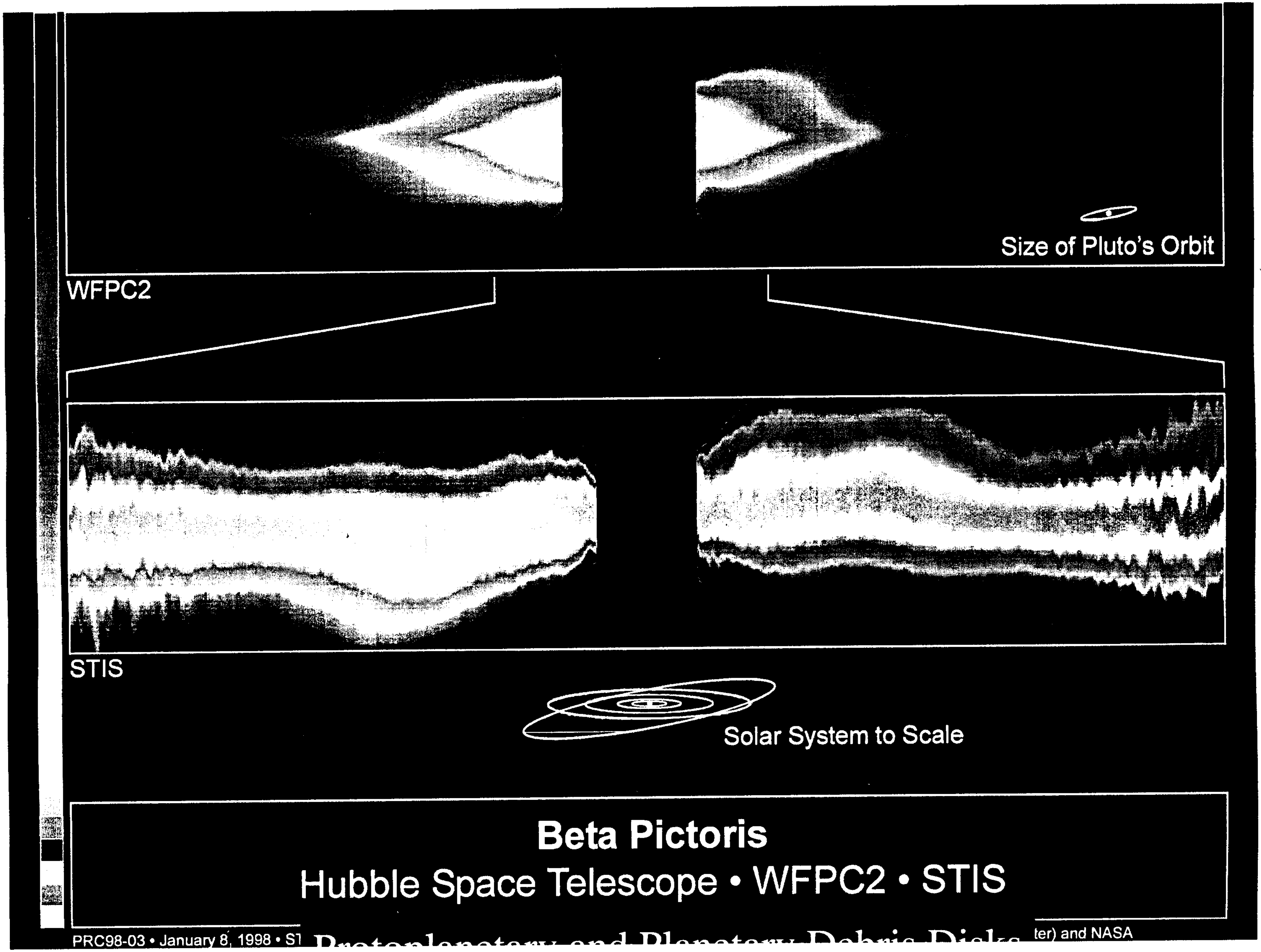


Palomar Observatory
Discovery Image
October 27, 1994



Hubble Space Telescope
Wide Field Planetary Camera 2
November 17, 1995

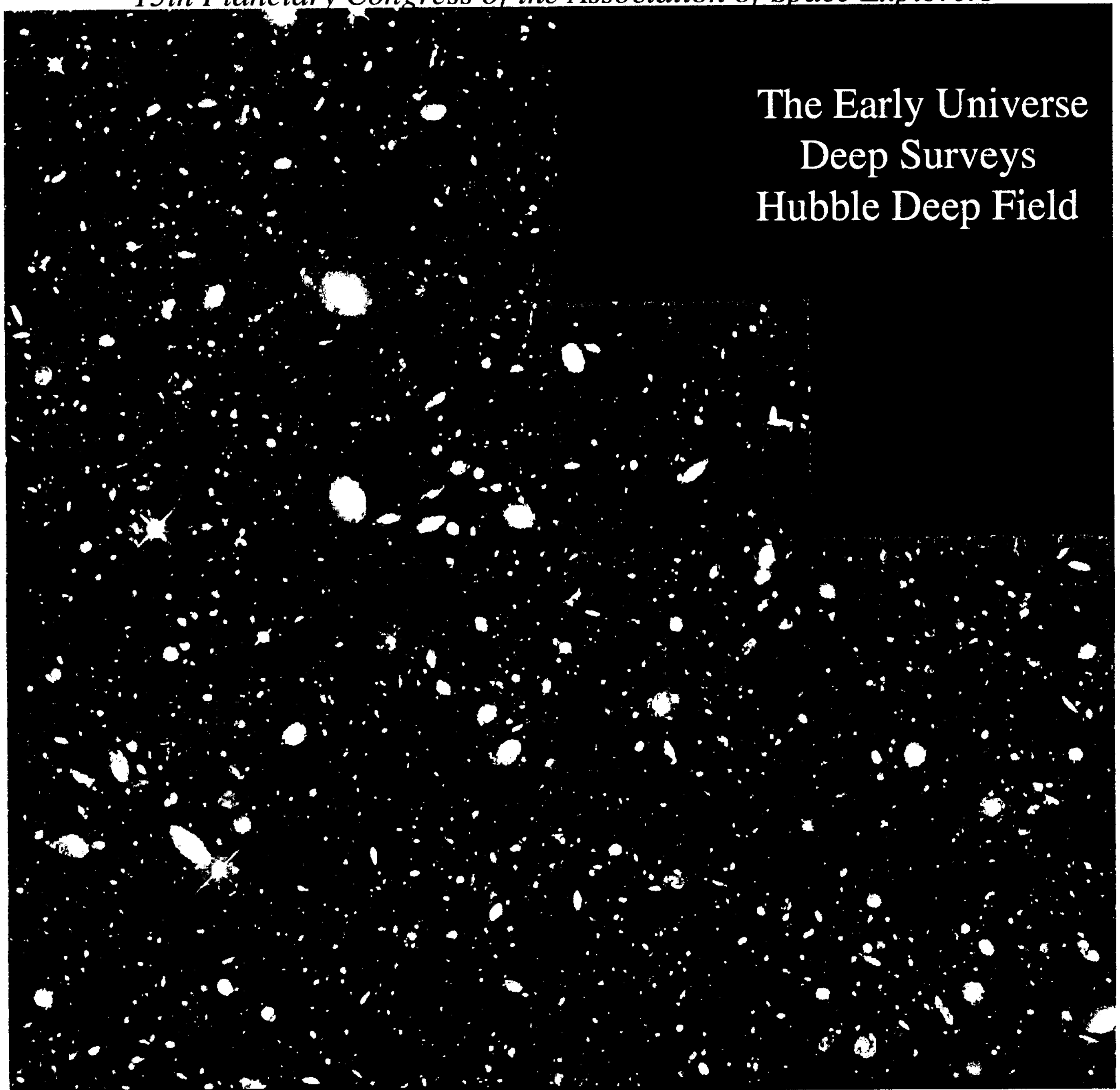
PRC95-48 • ST ScI OPO • November 29, 1995
T. Nakajima and S. Kulkarni (CalTech), S. Durrance and D. Golimowski (JHU), NASA



Protoplanetary and Planetary Debris Disks

SIRTF

Ultraluminous Galaxies and Active Galactic Nuclei
Antennae Galaxy NGC 4038 39


The Early Universe
Deep Surveys
Hubble Deep Field

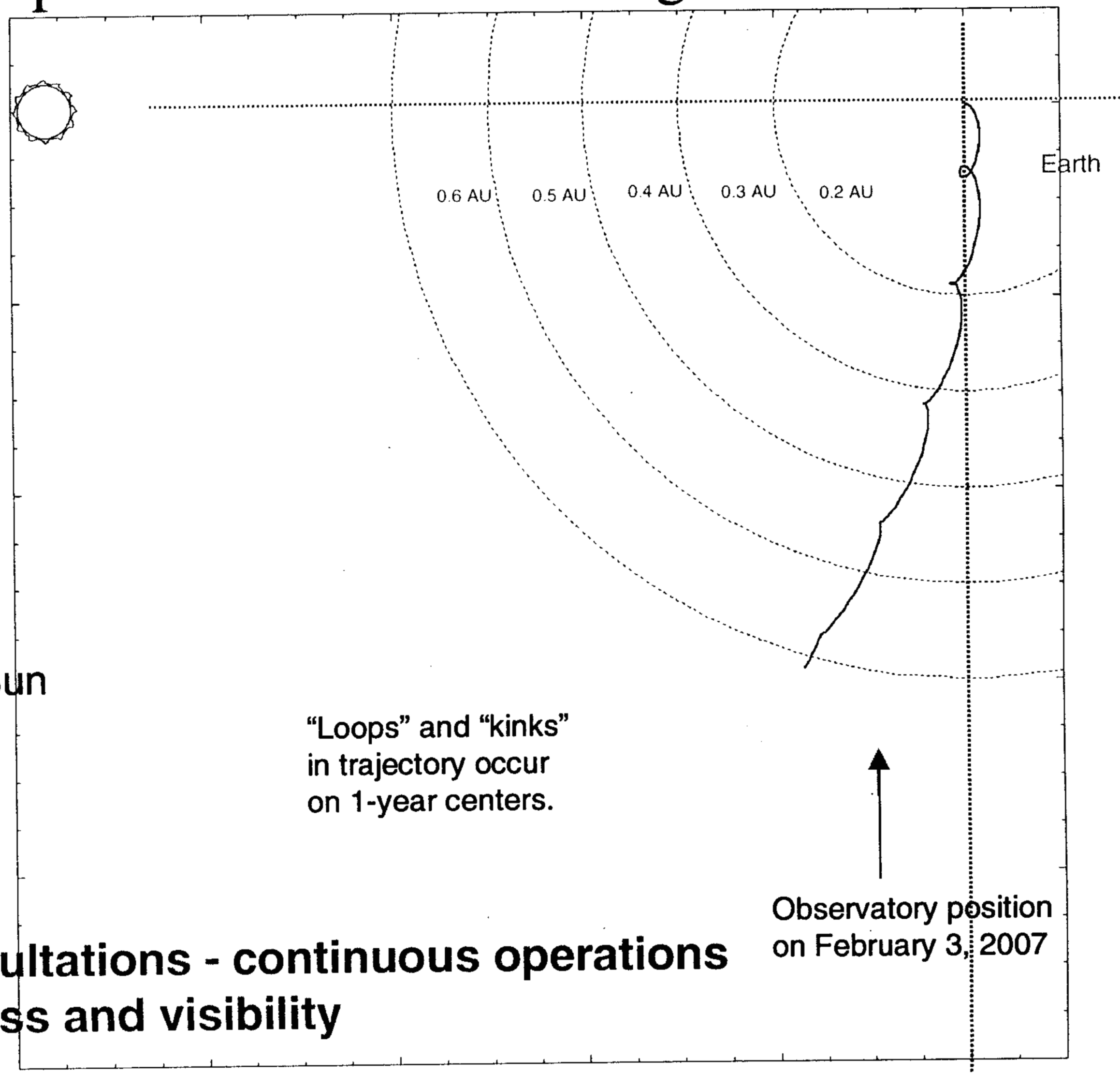
SIRTF

SIRTF - An Overview

- **Launch in December, 2001 for a 2.5-to-5 year mission**
- **Multi-purpose, liquid-helium and radiatively-cooled observatory**
  - 85-cm telescope, diffraction-limited @ 6.5um
  - Imaging, spectroscopy from 3.5-160um
  - Instruments use large-format infrared detector arrays
  - Innovative mission concept
    - *heliocentric orbit*
    - *warm launch*
  - >75% of observing time for general community
- **Builds on and extends results from IRAS, COBE, and ISO**
- **Completes NASA's Great Observatories; is a cornerstone of the Origins Program**

Solar Orbit

North Ecliptic Pole View in Rotating Frame



SIRTF's solar orbit projected onto the ecliptic plane and viewed from ecliptic North.

In the rotating frame, the Earth is at the origin and the Earth-Sun line is defined as the X-axis.

No eclipses or occultations - continuous operations
Excellent sky access and visibility

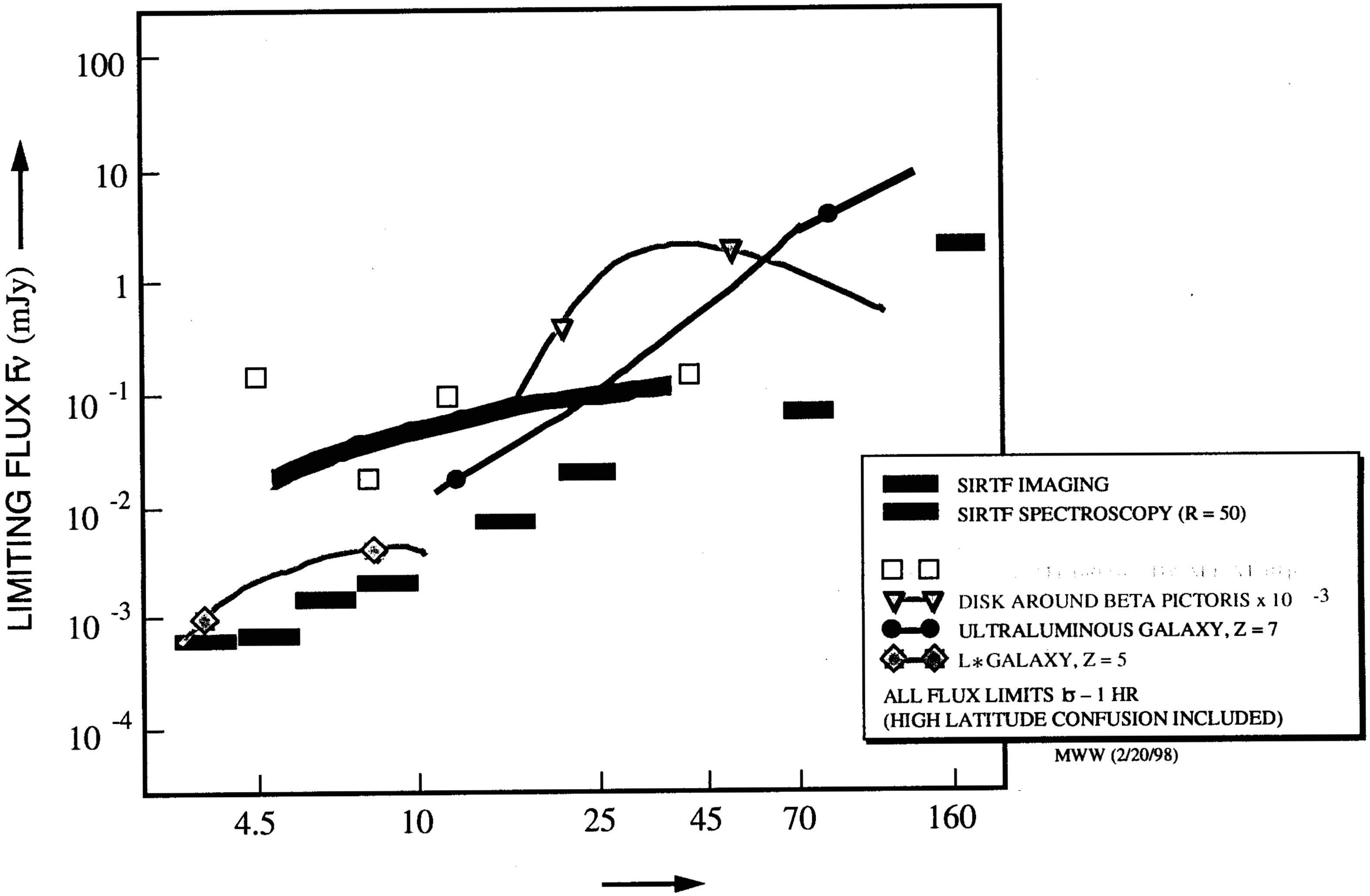
SIRTF Instrumentation Overview

- **Infrared Array Camera, G.G.Fazio, SAO, PI.**
  Wide-field (5x5 arcmin) imaging. Simultaneous viewing at 3.6, 4.5, 5.8, 8um
  InSb and Si:As IBC arrays, 256x256 pixel format

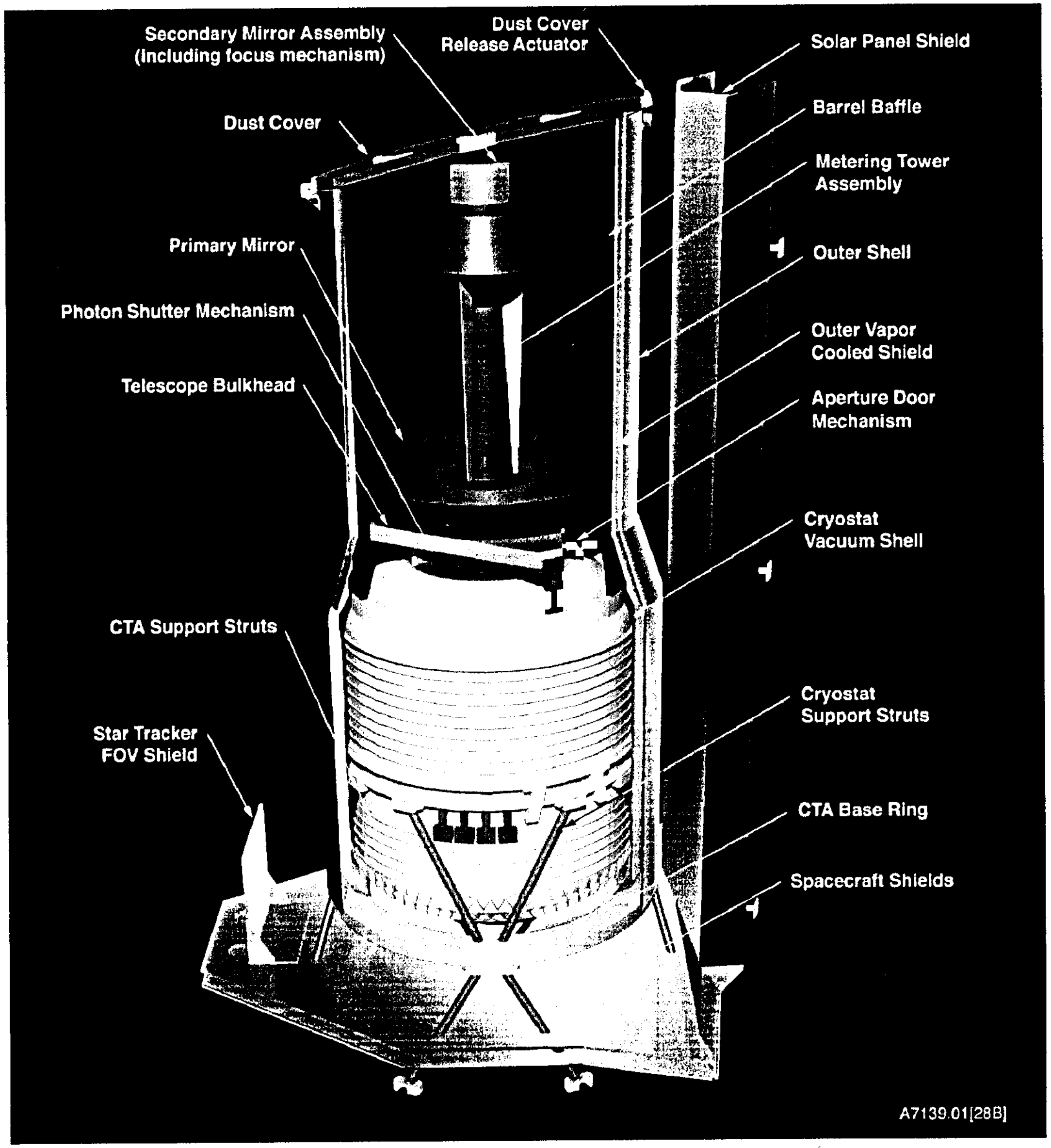
- **Infrared Spectrograph, J.R.Houck, Cornell, PI.**
  R= 600 echelle spectrographs, 10-20 and 20-40um
  R= 50 long-slit spectrographs, 5-15um and 15-40um
  Imaging/Photometry, 15um
  Si:As and Si:Sb IBC arrays, 128x128 pixel format

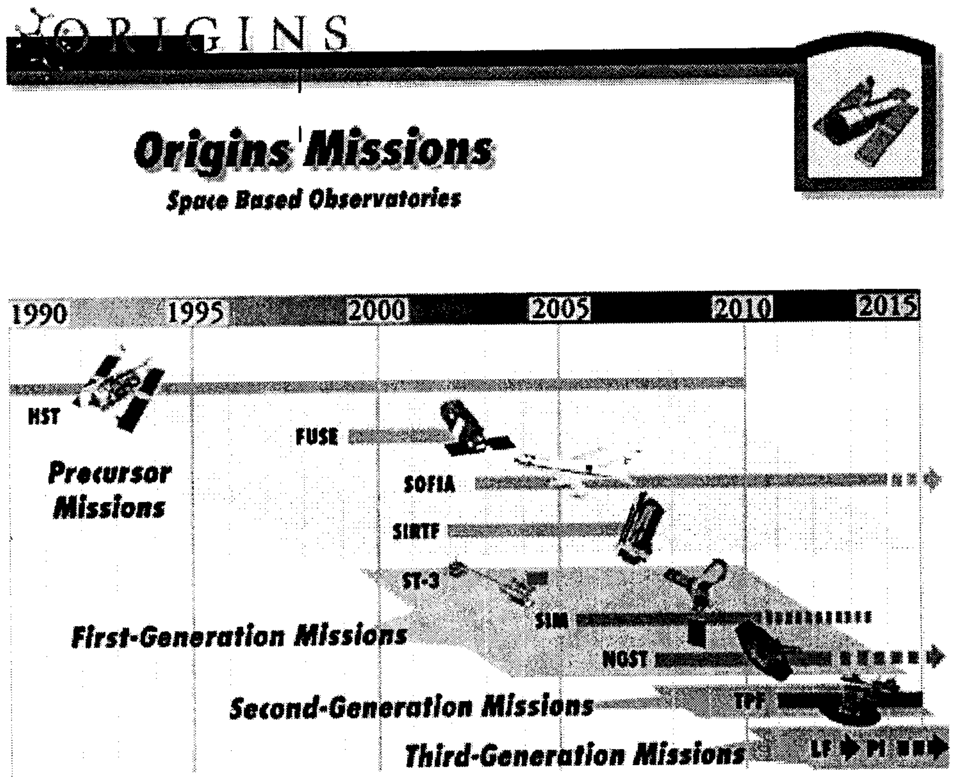
- **Multi-band Imaging Photometer for SIRTF, G.Rieke, Arizona, PI.**
  Imaging and photometry: 24, 70, 160um; optimized for efficient large area surveys and superresolution; R~15 spectrophotometry, 50-100um
  Si:As IBC and Ge:Ga arrays, 128x128 and 32x32 format
  Stressed Ge:Ga array, 2x20 format

SIRTF Performance Comparison



Warm Launch Architecture





http://origins.jpl.nasa.gov/missions/sbobs.html

MJD-22

Origins Timeline

What is SIM

- SIM is a space-based optical interferometer for precision astrometry
  - 10-m baseline, Michelson beam combiner
- Launch mid-2005, with a minimum 5-year mission lifetime
- SIM has 4 basic operating modes
  - Global astrometry
  - Local astrometry
  - Synthesis imaging
  - Fringe nulling demonstration for future missions
- How does it operate ?
  - SIM measures the white-light fringe position on 3 *simultaneous* baselines: 2 guides and 1 science
  - Using delay and angle feed-forward, the guides stabilize the science interferometer at the μas level

SIM

SIM Astrometric Performance Summary

- **Observational Band**: 400 - 1000 nm
- **Global (all-sky) astrometry**
  - Astrometric accuracy: 4 μas (end of mission)
  - Faintest stars: V = 20 mag
    - brightness of a solar-type star at 10 kpc
  - Yields distances to 10% accuracy, anywhere in our Galaxy
- Proper motion accuracy: 2 μas / yr
  - Motion due to parallax at 10 pc is detectable in a few minutes!

SIM

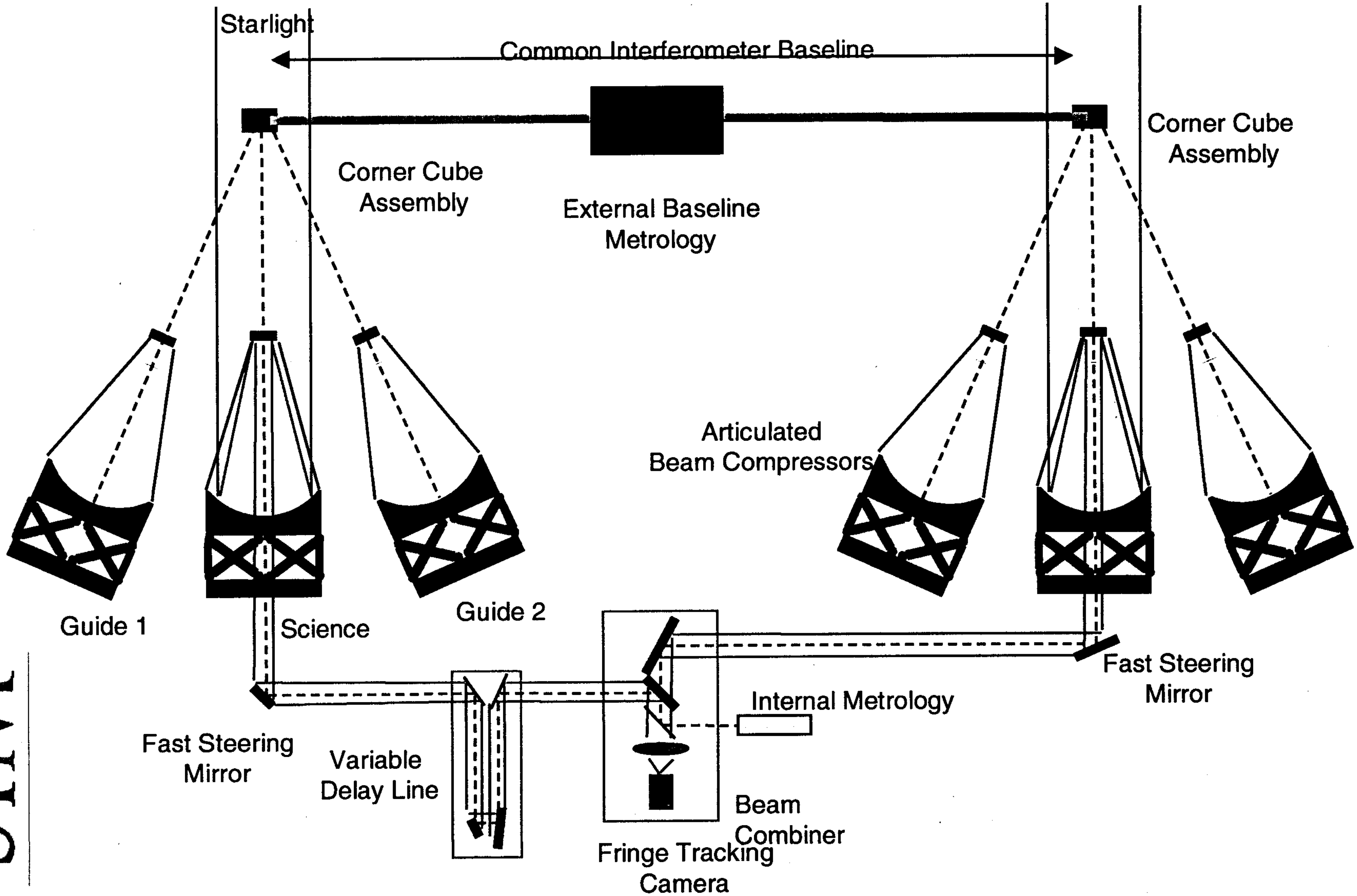
- **Local (narrow-angle) astrometry**
  - Measurements are made relative to reference stars (within ~1°)
  - Astrometric accuracy: 1 μas in one hour
    - This angle subtends a length of 1,500 km at 10 pc distance !
    - Detect proper motion of Barnard's star in 3s !

SIM science summary

- Search for astrometric signature of planets around nearby stars
- Distances to spiral galaxies using rotational parallaxes
- Mass distribution in the halo of our Galaxy
- Dynamics of our Local Group of galaxies
- Spiral structure of our Galaxy
- Calibration of the cosmic distance 'ladder'
- Ages of globular clusters
- Internal dynamics of globular clusters
- Masses and distances to MACHOs
- Accurate masses for low-mass stars in binaries
- Imaging of emission-line gas around black holes in active galactic nuclei
- Imaging of dust disks around nearby stars (nulling)

SIM

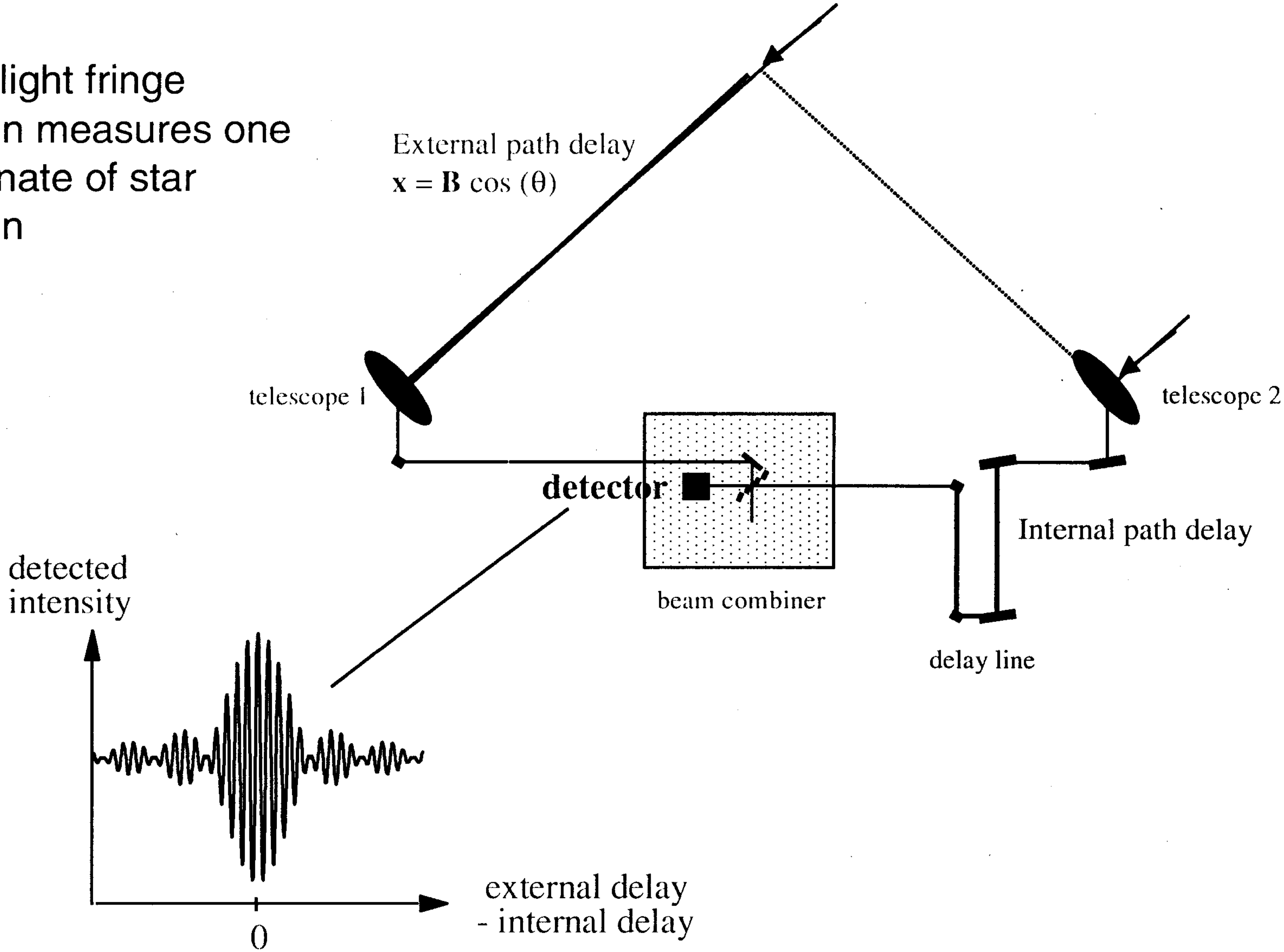
SIM Optical Layout - Triple Interferometer



SIM

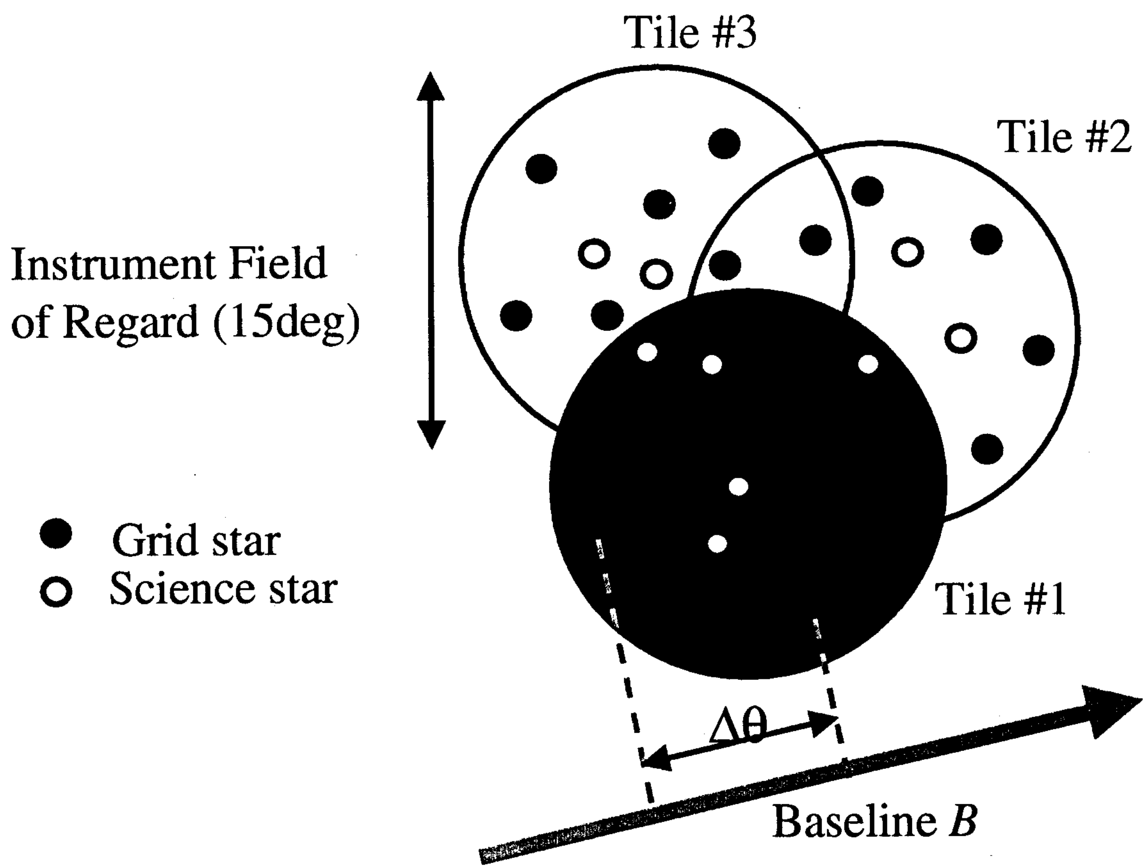
SIM Astrometric Measurement

- White light fringe position measures one coordinate of star position



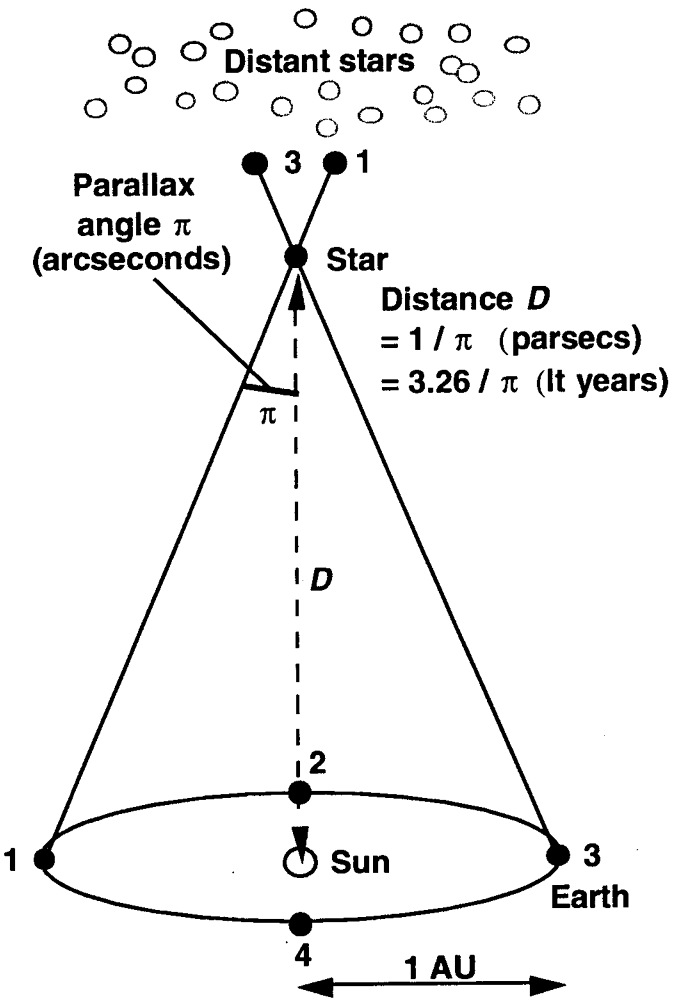
SIM

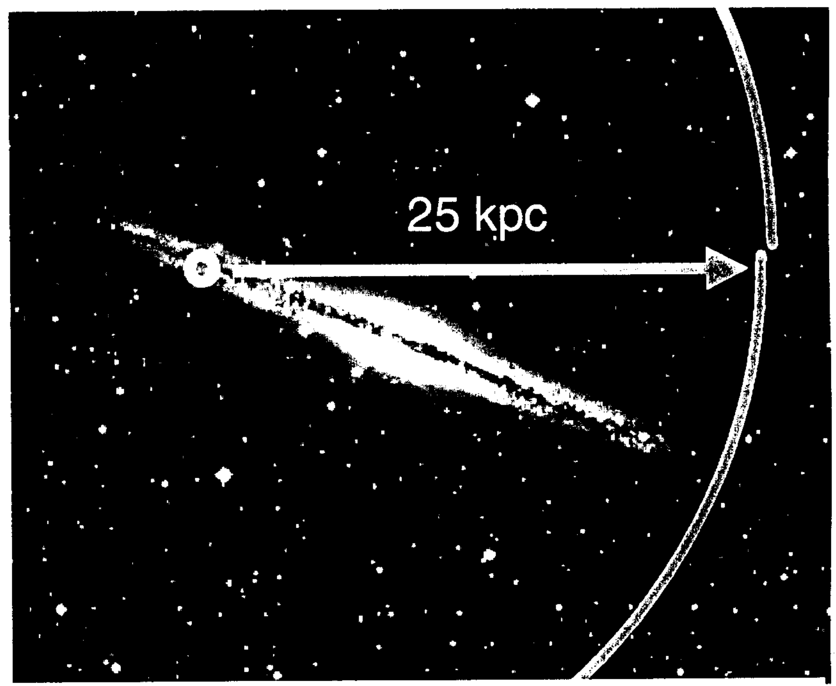
Observing Astrometric Grid Stars - 'Tiling' the Sky



SIM

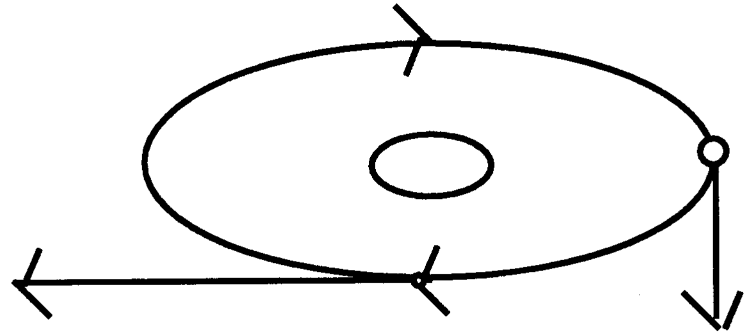
Measuring distances in the Galaxy





- SIM will measure parallax distances out to 25 kpc to 10% accuracy
- Distance to:
  - Hyades cluster 45 pc
  - Pleiades cluster 130 pc
  - Galactic center 8.5 kpc
  - Large Magellanic Cloud 50 kpc

Measuring distances to spiral galaxies using rotational parallaxes



Transverse velocity = $V_{rot} = \mu_{rot} D$

Radial velocity = $V_{rot} \sin i$
Transverse velocity = $V_{rot} \cos i$

- Measure distance to a galaxy in units of meters
  - 'Single-step' measurement
  - Calibration of **Tully-Fisher relation** (luminosity vs. peak rotational velocity)
    - Hence accurate distances for very distant galaxies
  - Accuracy ~5 % for disk galaxies out to ~ 5 Mpc
- Method: Astrometric measurement of galactic rotation
  - Example: M31 at 770 kpc. Rotational velocity (almost flat rotation curve) $V_{rot} = 250$ km/s $\Rightarrow$ 40 μas/yr
  - Select ~25 A-F supergiant stars along major and minor axes
  - Measure proper motions (μ_{rot}) using SIM - narrow-angle mode
  - spectroscopic radial velocities
  - Solve for distance from ratio of measurements of μ_{rot} and V_{rot}

SIM

Dynamics of open star clusters

- Internal dynamics of open star clusters (e.g. Pleiades)
  - Not restricted only to the closest clusters
- 3-D motions of a large sample of stars
  - trace mass distribution of the cluster -> total mass
  - 3-D orbits provide info on formation history and evolution
  - Cluster rotation?
  - Distribution of binary stars
  - Mass segregation

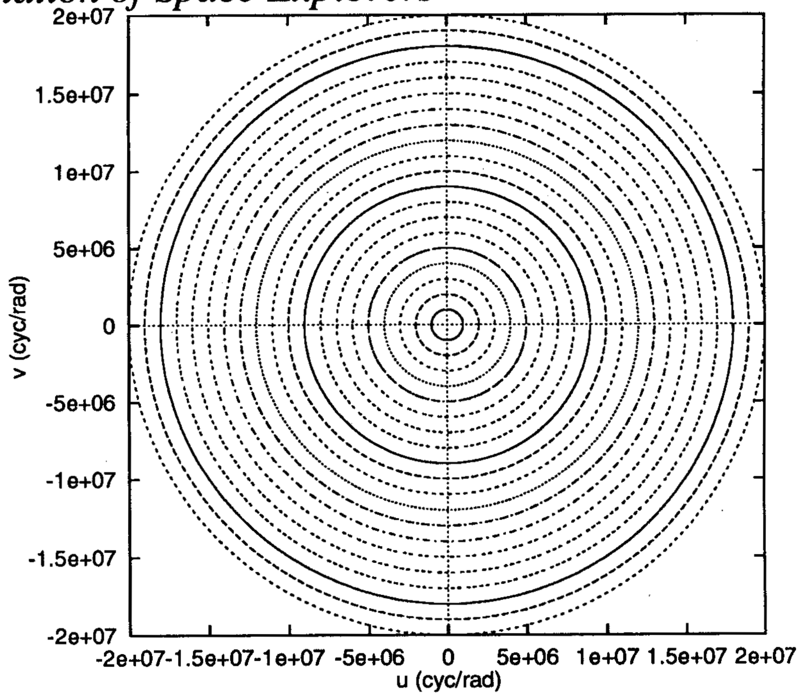
SIM

Galactic Dynamics

- Study the 'classical' problems of size, mass distribution, and dynamics of the Galaxy, using stellar velocities
- Questions include:
  - Vertical mass distribution of the Galactic disk, near the sun
  - Kinematics of the outer disk of the Galaxy (beyond R_o)
  - Kinematics of K giant stars in the outer halo - mass distribution
  - Understanding the central bar of the Galaxy
  - Debris tail orbits (Sagittarius dwarf galaxy) - phase space signature
- Method: derive 6-D phase-space coordinates for selected samples of stars:
  - Distances to 5% at 10 kpc, for stars with V < 20
  - Proper motions to 0.1 km/s at 10 kpc
  - Combine with ground-based radial velocities

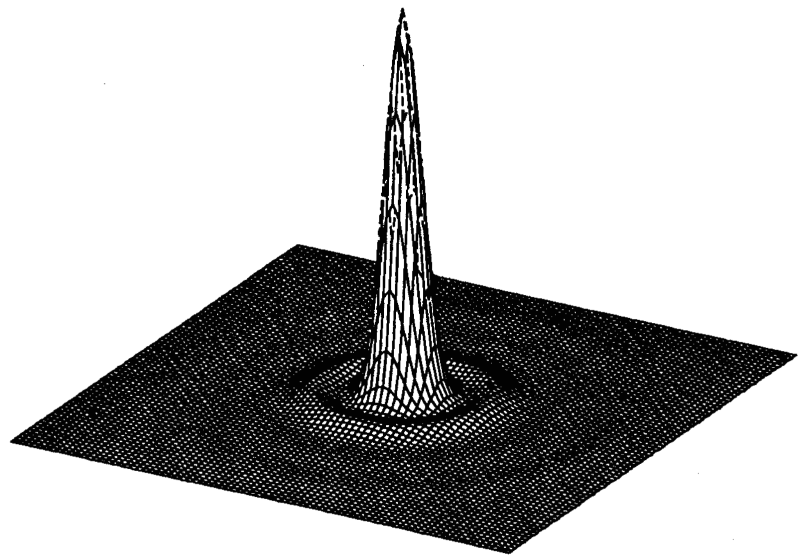
SIM

Imaging with SIM



- SIM forms images by
  - rotating the baseline around the line-of-sight to the target
  - Varying the baseline length to 'fill in' the (u,v) coverage

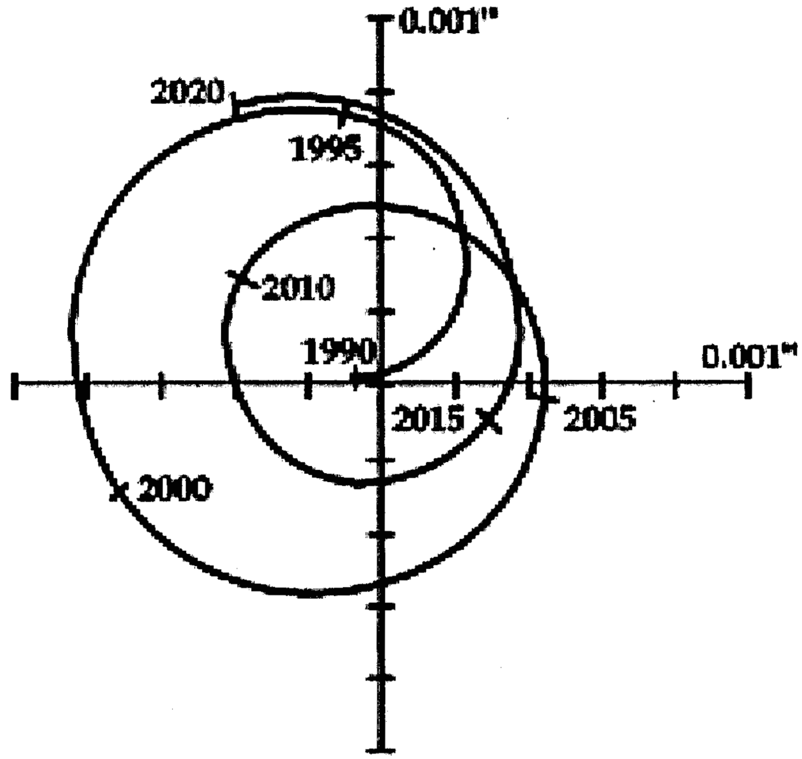
- Fourier transform amplitudes and phases to yield image



SIM

Searching for planets around other stars

- Questions:
  - Are planets around other stars common?
  - Are certain spectral types favored?
  - What is the mass distribution of planets?
- Method: astrometric detection of 'wobble' due to gravitational tug of <u>unseen</u> planets
- Jupiter-mass planets - signature is ± 5 μas at 1 kpc
  - very large number of targets
- Earth-mass planets - signature is 1650 times smaller (± 0.3 μas at 10 pc)
  - detectable only around the nearest stars



'Wobble' of the solar system as seen from 10 pc away (-1000 μas)

SIM Technology

SIM requires that three "grand technological challenges" be met and overcome:

(1) ***Stabilization of Optical Pathlength*** on a lightweight flexible structure to a nanometer in the presence of spacecraft vibration and thermal distortions, in order to maintain high fringe visibility.

(2) sub-nanometer level sensing of optical element relative positions over meters of separation distance;

Laser Metrology to measure critical interferometer component relative positional parameters over meters of separation distance to 200 picometer accuracy to enable microarcsecond astrometry.

(3) overall instrument complexity and the implications for interferometer integration and test and autonomous on-orbit operation.

Integration and Test of a complex interferometer instrument, its autonomous on-orbit operation and performance prediction.

The feasibility of meeting these technological challenges has already been demonstrated.

JPL is now moving beyond the feasibility stage toward implementing practical design solutions of space ready hardware and software.

SIM

Toward Future Missions

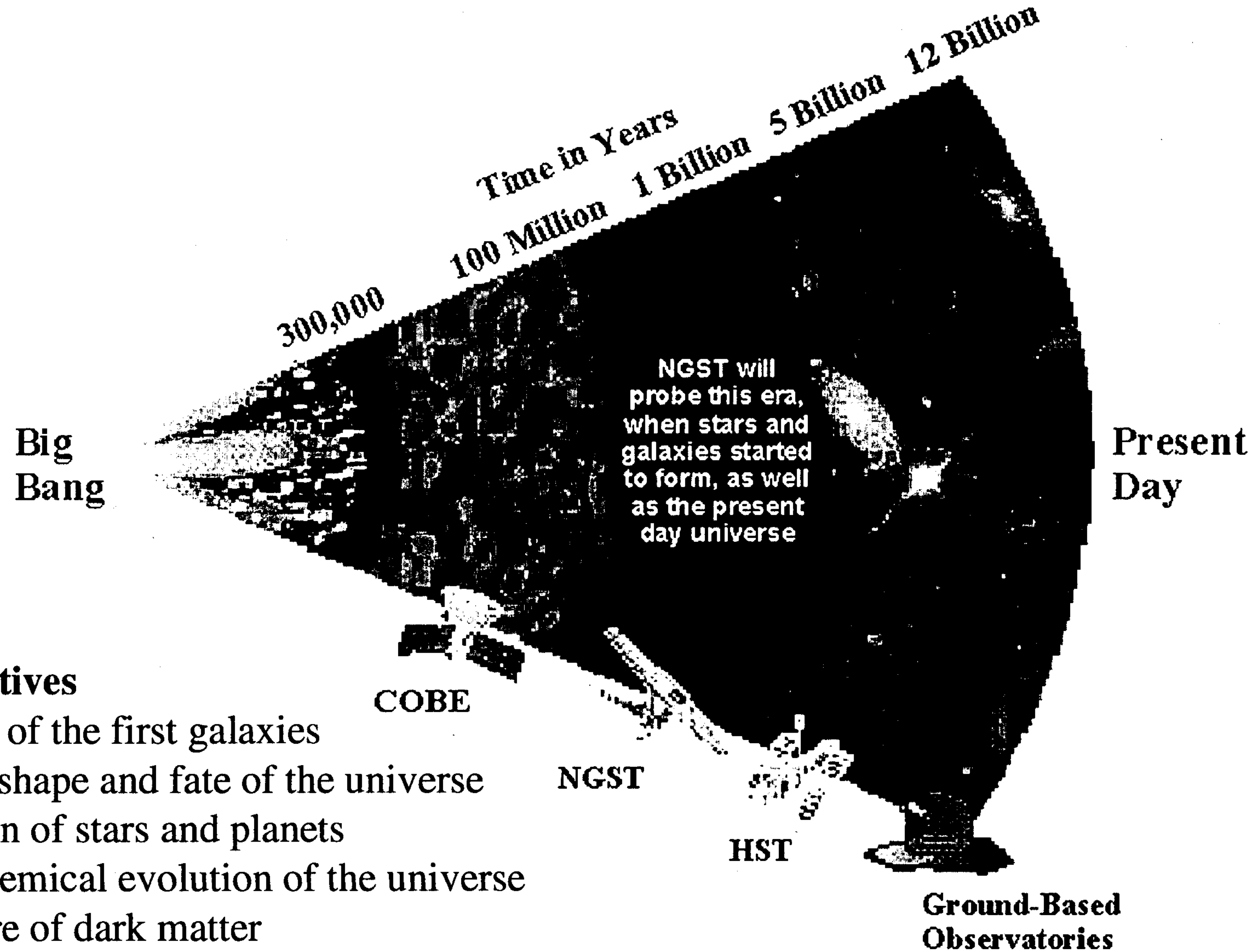
- SIM will serve as a technology precursor for future interferometers in space
- A direct precursor to the Terrestrial Planet Finder
- Demonstrate:
  - Operation of a Michelson interferometer in space
  - Fringe nulling
  - Control of thermal and vibration environment
  - Synthesis imaging in space
  - Precision deployments
  - Angle and pathlength control

SIM

15th Planetary Congress of the Association of Space Explorers

NGST Sees the First Stars and Galaxies

NGST



Science Objectives

Study the birth of the first galaxies

Determine the shape and fate of the universe

Study formation of stars and planets

Observe the chemical evolution of the universe

probe the nature of dark matter

Fig 001

Core Science Programs

NGST

Target Class	Study Objective	Target AB Mags.
Deep fields	One deep field (down to AB magnitude 32) and 100 deep less (AB 30) flanking fields will be observed in broad-band filters	30–32
Universe at redshifts $z > 2$	Primeval spheroids, birth and evolution of disks, the origin of heavy elements, birth and evolution of AGN	29 (near-IR) 26 (thermal-IR)
Supernovae study	Improve our knowledge of the geometry of the universe and study the material universe before the birth of galaxies	31
Stellar populations	Color magnitude to the horizontal branch luminosity both in the optical and in the near IR in the nearby universe	30.5–32
Cosmic distances	Studies, based on gravitational lensing and gravitational time delays, determine dark-matter distribution	27
Kuiper Belt object searches	Statistically meaningful study of their properties as well as of their distribution in space	30 (near-IR) 25 (thermal-IR)

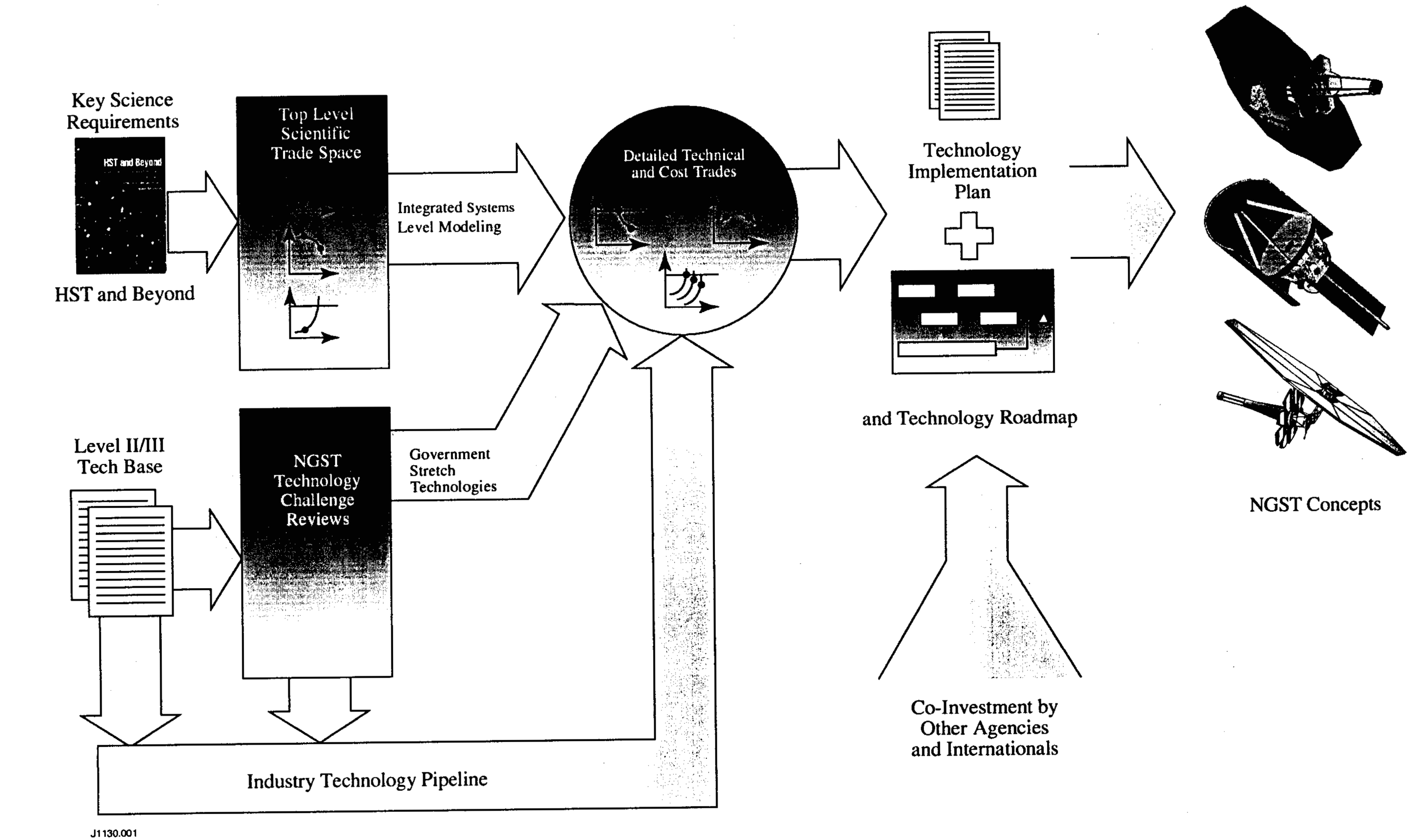
NGST Mission Profile

NGST

Parameter	Requirement	Goal
Wavelength range	1-5 μm	0.5 - 30 μm
Aperture diameter	> 4 m	> 8 m
Angular resolution	Diffraction-limited at 2 μm	Diffraction-limited at 0.5 μm
Spectral resolution	100 - 1000	100 - 3000
Optics temperature	< 60 K	30 K
Field of view	4' x 4' at 1 - 5 μm	Add 2' x 2' coverage 5 - 30μm
Sensitivity	Zodiacal background limited at 1AU orbit	Cosmic infrared background limited
Instantaneous sky coverage	100% available	
Lifetime	5 years	10 years
Orbit	L2 or 1 AU drift	1 x 3 AU

15th Planetary Congress of the Association of Space Explorers

NGST Mission Development Strategy



The NGST Challenge is to Use New Technology to Make the Mission Affordable

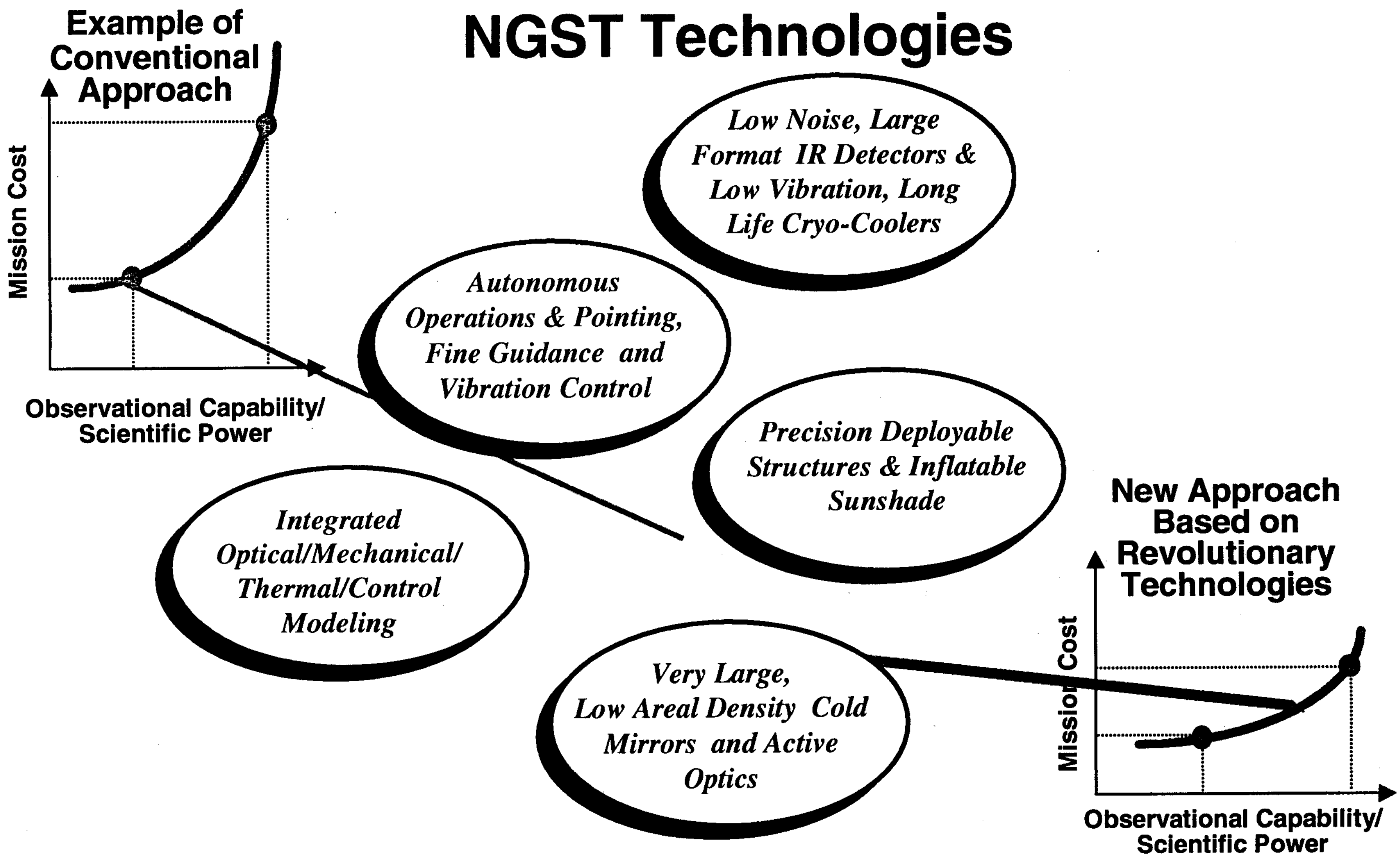


fig 035b

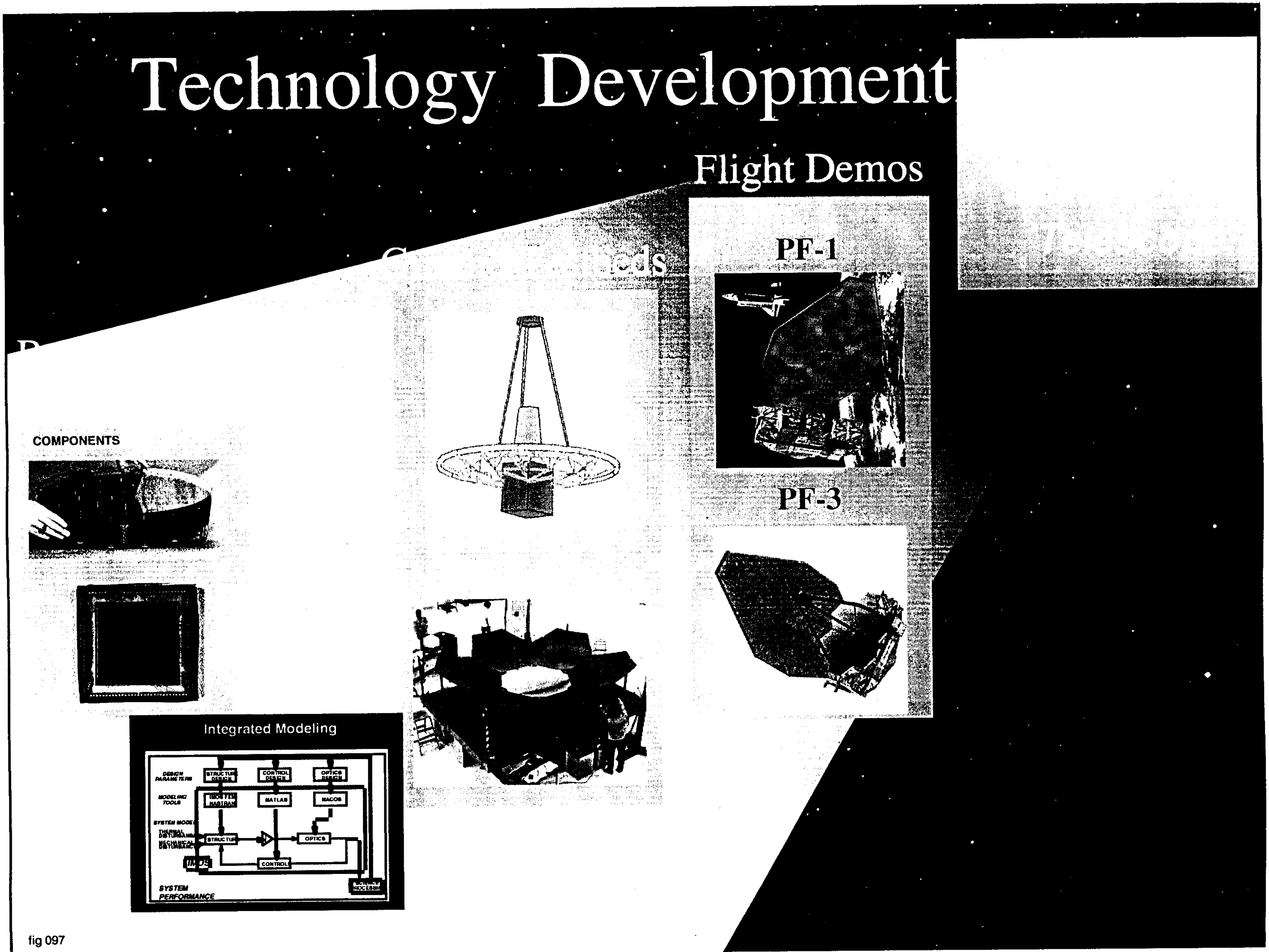
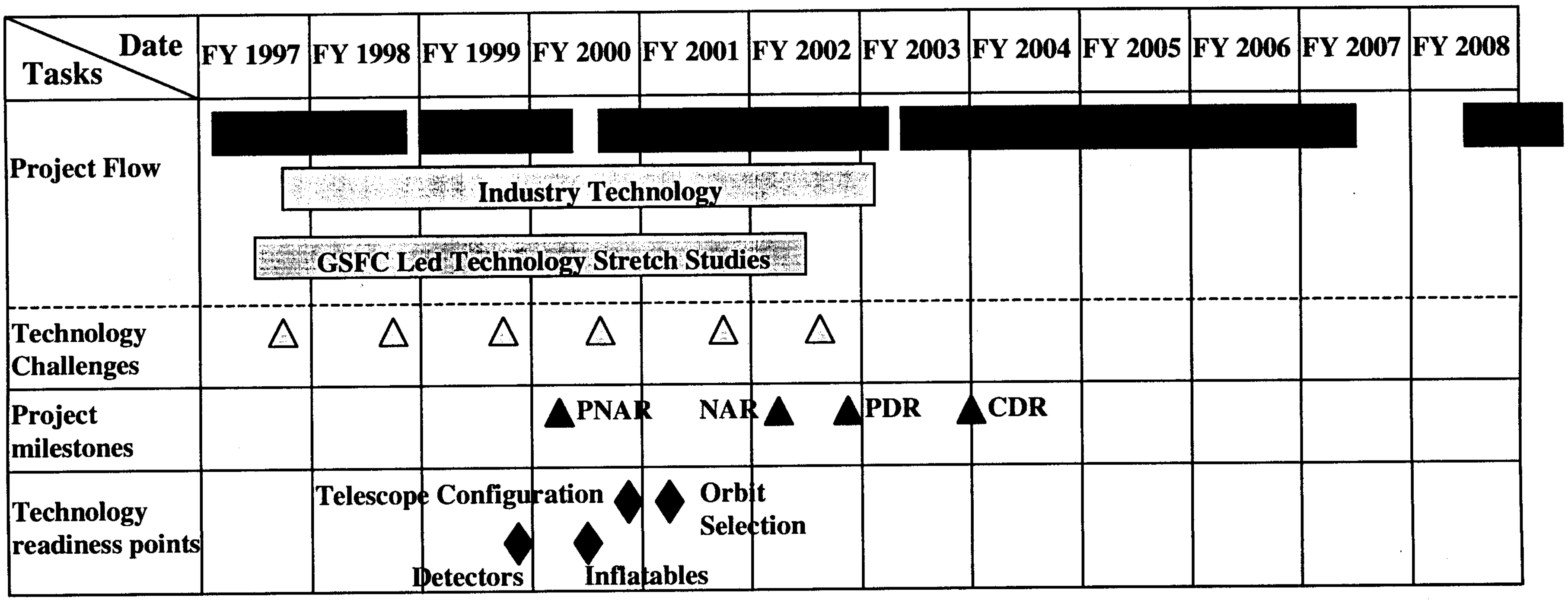

Technology Development
Flight Demos
PF-1
PF-3
COMPONENTS
Integrated Modeling
DESIGN PARAMETERS
MODELING TOOLS
CONTROL DESIGN
OPTICS DESIGN
MATLAB
MACOS
OPTICS
CONTROL
SYSTEM PERFORMANCE

fig 097

NGST Proposed TimeTable

NGST

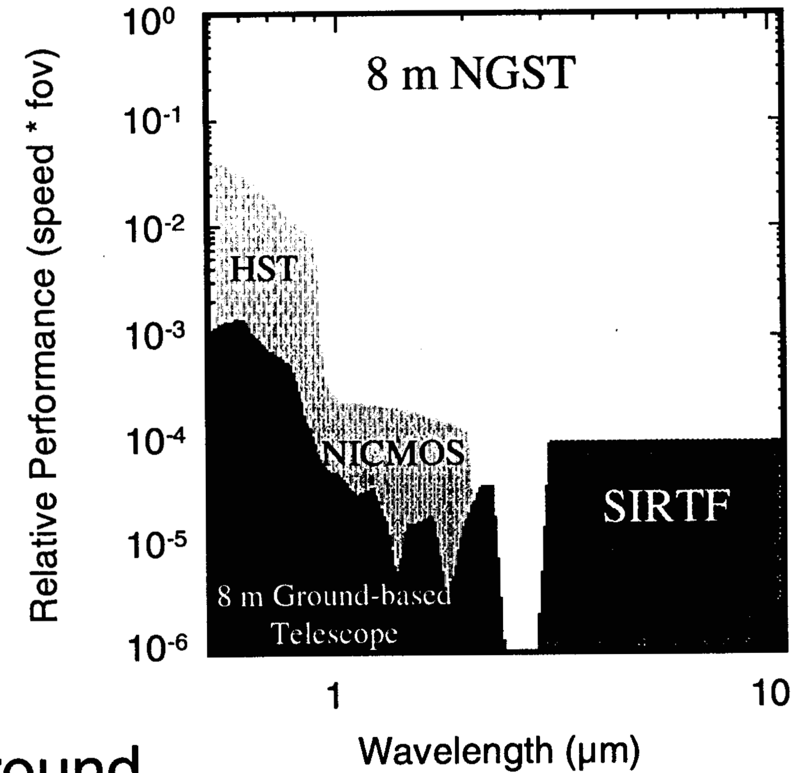


Relative Performance

- Low background and wide field of view yield 2-6 orders of magnitude speed increases the optical to mid-IR

- Performance scales as:

$P \propto \text{fov} \times (\text{Aperture})^2/\text{Background}$



NGST

Projected Sensitivity

- **WHAT SENSITIVITIES ARE NEEDED TO OBSERVE FAINT, REDSHIFTED LIGHT FROM DISTANT GALAXIES?**

- **PROJECTIONS FOR:**
  10000 sec. EXPOSURE
  S/N = 10σ
  $\lambda/\Delta\lambda$ = 3

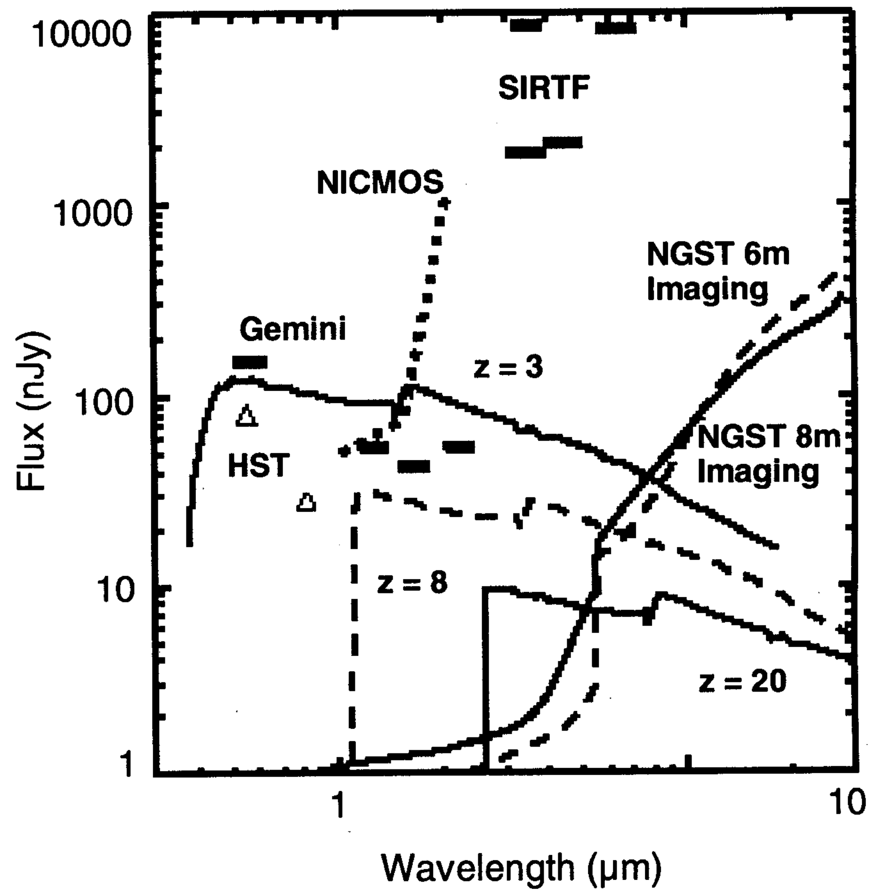


Fig 115

For additional information consult the following web sites

http://spacescience.nasa.gov/
http://origins.jpl.nasa.gov/
http://chandra.harvard.edu/index.html
http://ssc.ipac.caltech.edu/sirtf
http://sirtf.caltech.edu/
http://sim.jpl.nasa.gov/
http://ngst.gsfc.nasa.gov/
http://tpf.jpl.nasa.gov/